chpa

Bringing Energy Together

THE HEAT REVOLUTION

PUTTING CONSUMERS FIRST IN A DECARBONISED ECONOMY

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The UK needs a credible pathway for the decarbonisation of heat. Accounting for over half of our energy demand, heat is the Cinderella of the energy debate, central but often ignored. It is essential, however, that reducing emissions from heat be at the heart of energy policy if we are to achieve our decarbonisation ambitions.

Without active planning for heat, decarbonising the UK's energy demand is likely to be more costly, less efficient and represent poorer value to energy users at all scales. Starting with the needs of heat consumers, heat decarbonisation can be designed in a way that will facilitate both economic competitiveness and the decarbonisation of wider energy use whilst improving efficiency and security of supply.

This paper sets out an integrated energy story. The pathways for the decarbonisation of heat and power are considered together from the energy user's perspective. All scales, from rural householders through to urban communities and industry are considered. We divide heat use into three sectors: industrial, high density urban areas and lower density suburban and rural areas. For each, an integrated narrative is considered, exploring the full range of technologies and infrastructure available, to achieve an endpoint that meets the disparate needs of different users; be it high pressure steam in a chemical plant or hot water for a bath in a Victorian cottage.

Cost effective decarbonisation of energy use is fundamentally achievable. But, as with power, we need to start on this journey now. This paper maps the journey, presenting a vision of the transition to an economy in which low carbon energy is delivered to all, meeting consumers specific requirements.

Rural and suburban heat

Profile:
Rural - Low density buildings, many hard to insulate with no gas grid connection.
Suburban - Medium density buildings, with access to gas and electricity grids.

Now
Fossil fuelled boilers and electric heating dominate.

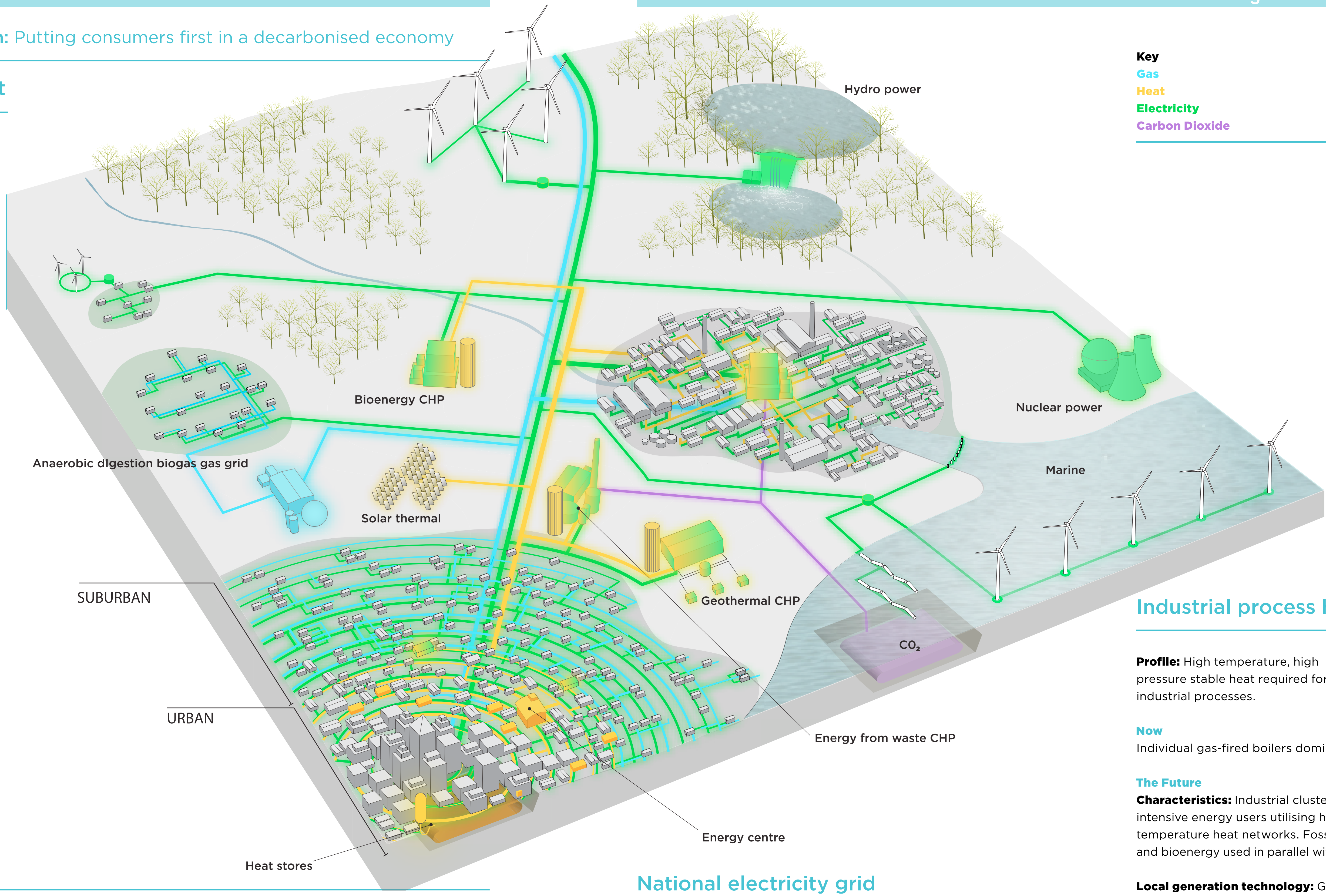
The Future
Characteristics:
Rural - Local bioenergy resources. Individual onsite solutions bespoke to building characteristics.
Suburban - A combination of individual solutions, utilising gas and decarbonised grids.

Local generation technology:
MicroCHP (combined heat and power), heat pumps, solar (thermal and photovoltaic [PV]), small scale wind.

Resource inputs: A diverse array including solar, wind, air, ground, bioenergy, waste, decarbonised grid electricity, some natural gas.

Networks: Electricity distribution grid and gas grid (using biogas) in some areas.

Consumption: Decarbonised gas and electricity used onsite. Smart grid with generation (CHP, PV, wind) and consumption technologies (heat pumps [HPs], electric vehicles [EVs]) interacting to balance local electricity grid.



Key
Gas
Heat
Electricity
Carbon Dioxide

Dense urban areas

Profile: High density residential and commercial buildings.

Now
Individual gas boilers in most homes and businesses. Electric heating in tower-blocks and some flats.

The Future
Characteristics: A community-scale approach; heat networks with varied heat sources and large scale thermal stores.

Local generation technologies:
Large-scale, high-efficiency heat pumps, community-scale CHP, electric boilers, limited microgeneration.

Resource inputs: A diverse array of solar, ambient air, ground and water energy, geothermal, waste, bioenergy and residual natural gas. Electricity from low carbon centralised and local generation.

Networks: Electricity and heat with some natural gas.

Heat storage: Large-scale heat storage including short-term and inter-seasonal.

Consumption: Two-way (smart) grid integrating electric vehicles and heat pumps as well as traditional demand usage. Heat storage and generation technologies exploited to balance local electricity grid at times of high and low demand.

National electricity grid

Now
Predominance of fossil fuels. Electricity centrally generated far from point of use.

The Future
Characteristics: Decarbonised with greater decentralised generation, located closer to point of demand.

Technologies: CHP, wind, hydro, marine, nuclear, bioenergy, carbon capture and storage (CCS).

Resource inputs: Intermittent renewables; baseload nuclear and fossil CCS; flexible biomass and fossil.

Networks: Electricity and gas with international interconnectors, heat and CO_2.

Industrial process heat

Profile: High temperature, high pressure stable heat required for industrial processes.

Now
Individual gas-fired boilers dominate.

The Future
Characteristics: Industrial clusters of intensive energy users utilising high temperature heat networks. Fossil fuels and bioenergy used in parallel with CCS.

Local generation technology: Gas and bioenergy with CCS, electricity for very high grade heat.

Resource inputs: Waste, gas, biomass, biogas (either grid or locally generated), decarbonised electricity supply or onsite generation.

Networks: Electricity, gas and high temperature heat networks.

Consumption: Heat and power used in industrial processes.

Industrial processes

Overview

“High temperature heat networks serving industrial clusters exploit economies of scale, mitigate investment risk and enable economic deployment of industrial CHP and CCS infrastructure”

Consumer profile
The industrial consumer’s overriding concern is competitiveness. As many industrial processes are heat intensive, the cost and reliability of heat supply is central to business. These drivers are now joined by a third; as we move to a decarbonised economy, heat must also be low or zero carbon.

The high temperatures required by individual processes is currently provided by individual gas-fired boilers or, for the highest temperatures, electricity. Whilst electricity from the grid will decarbonise over time, the relatively high cost of electricity makes it unsuitable for widespread heat generation as this would make much of industry uncompetitive; its use is best limited to very high temperature processes such as iron and aluminium smelting.

For medium temperature industrial heat needs, fuel combustion is likely to be more cost effective than using electricity for heat. There are, however, some challenges to the decarbonisation of this fuel: the biomass supply chain is currently immature and biomass also requires sizeable onsite storage, the use of fossil fuels will need to be married to costly CCS infrastructure, and a continued rise in fuel costs will also increase costs of production. A cost and energy efficient range of solutions is therefore needed.

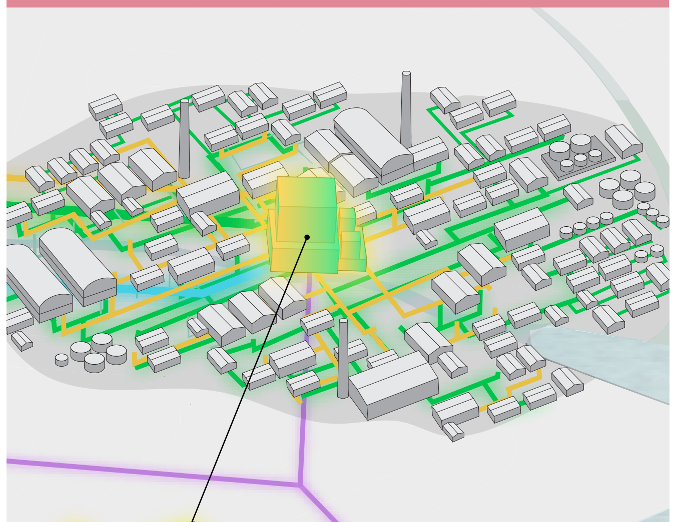
Decarbonisation
High temperature steam networks can address many of the industrial energy challenges. Industry clusters allow heat networks to utilise the combined heat demand of multiple users to deliver cost efficiencies in heat provision. By serving multiple users investment risk is reduced, facilitating industry growth by lowering the cost of capital.

At this scale steam heat networks can integrate a range of generation technologies, enabling network operators to arbitrage between energy sources and optimise their heat provision. Generation technologies and infrastructure can evolve over time, starting with energy efficiency such as gas CHP plant, and moving waste and renewable fuel. CHP will not only optimise fuel use but will also shield industry from wider electricity policy cost, driving continued international competitiveness.

Heat can also cascade between uses. Either on the same site or via a network, processes requiring high temperatures can pass lower temperature ‘waste’ heat to a secondary user. Despite improving the efficiency of industrial processes, reducing and reusing waste products, there is often low temperature heat (below 100°C) which has no further industrial application. In an integrated future, this waste heat can be supplied to a community heat network for local homes, public and commercial buildings.

To achieve subsequent deeper decarbonisation, unavoidable process emissions can be tackled by capturing carbon and storing it underground. Industrial clusters allow CCS infrastructure to be concentrated at fewer sites with costs shared among several users.

Working for the economy, the consumer and the energy system
Much of UK industry is already regionally clustered so connecting multiple users on a network is not necessarily limited to new developments. These industrial clusters or energy parks may also serve to attract new industry through reduced energy costs and carbon emissions. It is only through cost and energy efficiency, that competitive industry in a decarbonised economy is achievable.



CHP supplying industrial cluster with heat and exporting electricity to grid.

Where is it happening?

High-grade industrial heat network: Sembcorp Wilton International

- Seven industrial users, SABIC, Huntsman, Lotte, Ensus, Wilton Centre, Hertel and Sembcorp, clustered at one site served by a high grade heat network.
- Two power stations producing 228 MWe of power and up to 550 tonnes of steam an hour.
  - A 194 MWe coal and gas-fired CHP plant with an overall efficiency rating of 70%. Over its lifetime saving 20 million tonnes of CO_2.
  - A biomass CHP plant with heat recovery, capable of producing enough electricity to power around 50,000 homes.

Use of waste heat and CO_2: British Sugar’s Wissington site

- Largest sugar beet factory in the world
- 70 MWe capacity CHP plant providing all steam and electricity for the site’s core sugar production operations and exporting 50 MWe of low carbon electricity to the local network; meeting the electricity needs of 50,000 homes.
- Steam saved from process efficiencies used in bio-refinery producing 55,000 tonnes of bioethanol per year.
- Low-grade waste heat and CO_2 supplies one of Europe’s largest glasshouses to grow over 80 million tomatoes each year (about 10% of UK tomato demand).

Sembcorp Wilton International

Now:
Individual gas boilers, some CHP

Industrial steam networks. More gas and renewable CHP

Future:
Industrial clusters with CCS CHP. Decarbonised electric heat.

Dense urban areas

Overview

Consumer profile
As with all energy users, those in urban areas need affordable heating, hot water and, increasingly, cooling. Urban areas, however, are characterised by a diverse mix of buildings, many of which are older and costly to insulate, with some protected by listed or conservation area status. These densely packed areas also have a wide array of building uses including domestic, commercial and public buildings. Currently, individual gas-fired boilers predominate but this will need to evolve as towns and cities decarbonise.

High densities and high land values restrict the space available for fuel delivery, storage and heat storage. Air quality and noise regulations further limit the suitability of individual solutions such as heat pumps or biomass boilers in urban environments.

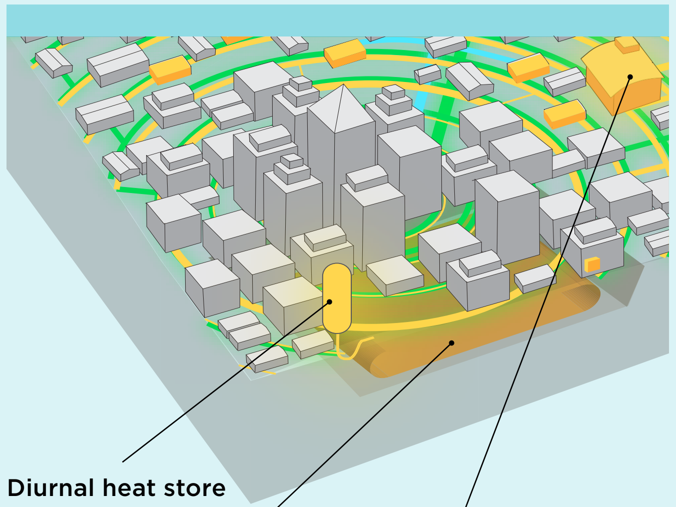
Decarbonisation
In high density areas, heat networks are the most efficient mechanism by which to decarbonise heat. Heat and cooling infrastructure consists of systems of underground, insulated pipes, which transport hot or cold water, from energy centres to end-users. As with other networks, heat networks can operate with a range of heat sources including large-scale heat pumps, boilers and CHP (fossil fuel, energy from waste or renewable) and waste heat from industry. Such an integrated approach to energy use avoids technology or fuel 'lock-in' as heat generation technologies can evolve over time. Working at this scale allows integration of larger heat sources, such as energy from waste plants, and employs technologies at community scale with higher efficiencies than their smaller building scale alternatives.

Working for the economy, the consumer and the energy system
Individual heating solutions are sized to be able to meet the infrequent maximum heat demand of a property. The sum of these individual peak demand capacities, however, is greater than the generation capacity required by shared heat provision. The variety of users on a heat network, homes and businesses, ensures that the timing of peak demand from different heat users does not occur at the same time. This reduction in generation capacity as well as fuel use allows capital and energy to be employed more efficiently.

A feature of the UK's decarbonisation pathway is a likely increase in electricity demand, as new applications such as domestic heat pumps and electric vehicles, could increase the peak demand on the system. By linking heat and electricity, domestic heat pumps in urban areas could lead to increased peak demand requiring costly upgrading of the local and national electricity networks. The capability to separate in time the production and consumption of heat offers the means to mitigate these peaks in electricity demand and can be achieved through highly efficient, large-scale heat stores connected to heat networks. Heat could be generated off-peak (e.g. weekdays for industrial or daytime for solar thermal), and accumulated in a thermal store for supply to users via the heat network as and when they require it.

Thermal storage on a heat network can also play an active role in facilitating the decarbonisation of the power network. On a windy night as wind turbines ramp up, national power generation may exceed demand. Without the option of low-cost electricity storage, this situation is presently considered as an operational problem for grid operators. However, with the availability of thermal stores, electric boilers can readily absorb excess power and convert it to heat which is stored for future use. Likewise, at times of peak demand, heat pumps can be switched off (reducing demand) and CHP can generate additional electricity and heat locally. In this way, thermal storage and CHP can provide an economical buffer to manage future variability in electricity generation and demand.

The combined benefits of networked heat and thermal storage offers the prospect of a more cost-effective system, meeting consumers' needs and driving wider energy decarbonisation.



Diurnal heat store

Interseasonal underground thermal storage

Diverse community scale heat generating technologies such as heat pumps, CHP (gas or renewable), solar thermal and biomass boilers in energy centres across the heat network. Electricity from CHP exported to grid.

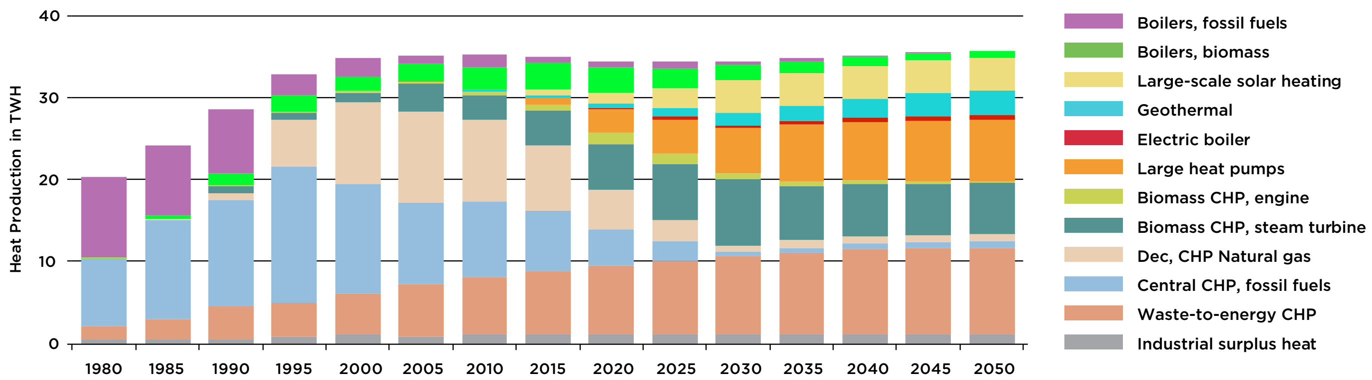
"As well as being suitable for hard to insulate properties, heat networks are fuel and technology neutral and, coupled with thermal storage, can provide balancing services to the electricity grid"

Where is it happening?

Large-scale deployment of district heating and CHP: Denmark

- Since the 1970's Denmark has seen widespread deployment of CHP, district heating and energy from waste.
- The diversity of heat sources on the networks has increased over time and has also seen a shift to lower carbon technologies (see graph below).
- More recently, as offshore wind has been built, the district heating network has provided grid balancing for intermittent renewables.
- Studies have identified that the Danish district heating network will expand from its current 50% to cater for 65% of the heat market, with small scale networks covering 5% and the remaining 30%, with no network access, served by heat pumps.
- As the heat networks grow over time, the total heat output required will stabilise as building energy efficiency reduces the demand per dwelling.

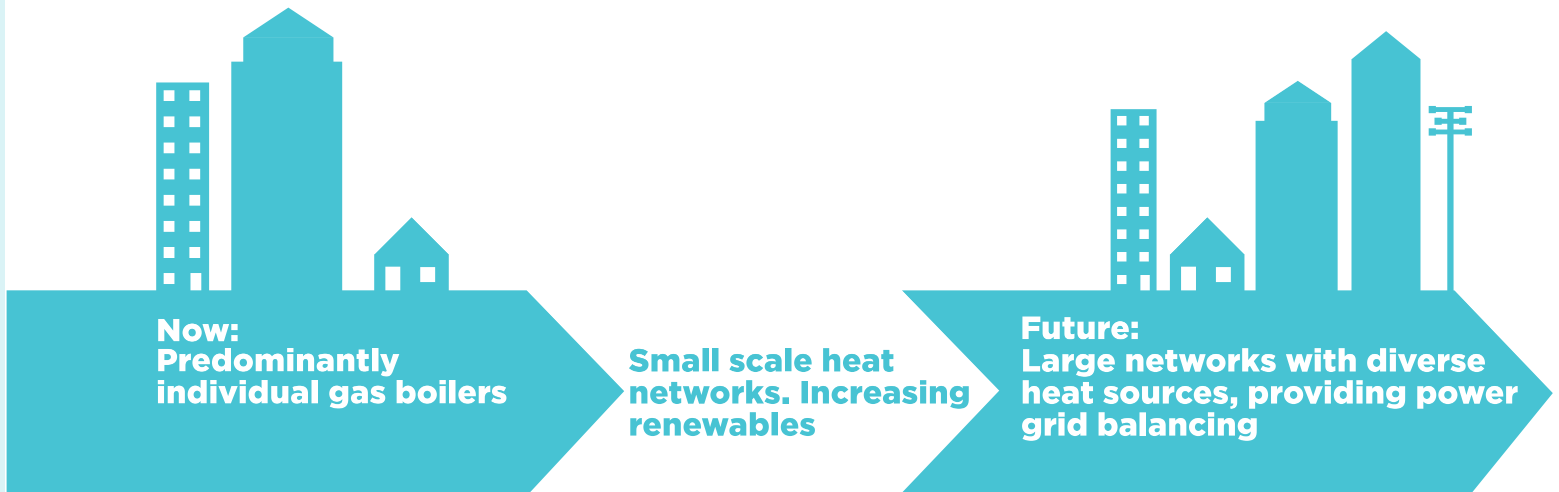
The graph below illustrates how the heat sources on the networks have changed over time and will continue to reduce carbon emissions. Predictions suggest the system will be CO_2 neutral before 2030 and independent of fossil fuels by 2050, even, as energy demand doubles.



Changes in heat sources across Denmark's district heating networks: Source Rambøll and Ålborg University.

Campus combined cooling heat and power (CCHP): MediaCityUK, Salford Quay Manchester Peel Group

- Europe's first purpose built creative and media development, one of the UK's largest construction projects at £500 million.
- A 2 MW natural gas CHP engine provides both power and heat with additional heat provided by two 9 MW gas boilers.
- 2,000m of pre-insulated underground heat network piping.
- Surplus heat is used in a 1.5 MW absorption chiller, providing a cooling service to buildings.
- This tri-generation (power, heating and cooling) energy scheme results in energy cost savings of £560,000 each year and delivers at least a 29% reduction in emissions – approximately 20,000 tonnes of CO_2 per annum.



Medium and low density areas

Overview

Consumer profile
The heat user in suburban and rural areas has the same need for warm homes and buildings as the urban user but within an entirely different setting. Buildings are more dispersed and the range of building types spans ageing, listed farm cottages to highly insulated modern offices. In areas off the gas grid, electricity, oil, coal and LPG (liquified petroleum gas) meet heating needs, although the higher cost of these fuels (in comparison to gas) has led to a higher incidence of fuel poverty. In surburbia, heating is driven by the gas network.

Decarbonisation
Improving building and boiler efficiency, including use of microCHP (combined heat and power) in larger homes, can deliver significant carbon savings. Newer buildings with excellent thermal properties, or older buildings where insulation has been retrofitted to a high standard, are ideally suited to heat pumps which concentrate heat from the air, ground or bodies of water. The relatively high thermal efficiency of these buildings enables them to accommodate the lower temperatures of heat pumps and exploit their efficiencies.

In rural areas especially, there is a significant number of hard-to-treat buildings unsuited to insulation. Here, low carbon options such as biomass and biogas boilers and LPG

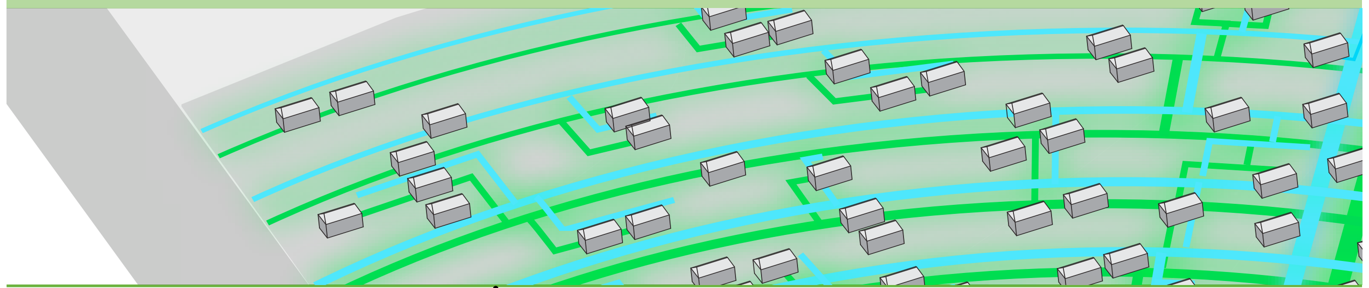
Suburban

Ground source heat pump | Air source heat pump, solar PV and solar thermal | Gas microCHP

Where is it happening?

Modulating CHP combined with heat pumps: Townhill Primary School, Hamilton

- Small project not suited to traditional CHP, but ideal for SAV LoadTracker modulating CHP combined with air source heat pumps, the latter powered by low carbon electricity from the CHP.
- Two 15kWe CHP units combined with two air source heat pumps to supply hot water and electricity – reducing carbon emissions by 26%.
- Each CHP unit modulates to 40% of its full electrical output to track site demand for lighting and power, as well as driving heat pumps, thus minimising use of carbon-intensive grid electricity.
- Heat from CHP fed through heat exchangers for heating and domestic hot water, supplemented by heat pumps.



Medium density housing on gas and electricity grid

Suburban

Now: Predominantly individual gas boilers

Further deployment of 'A-Rated' boilers, microCHP and heat

Future: Significant deployment of heat pumps

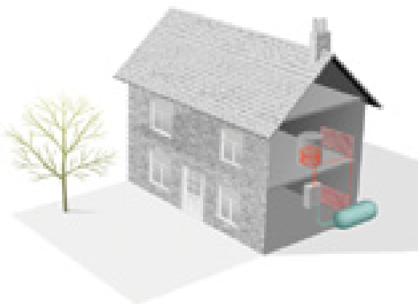
microCHP are better placed to serve their heat demands, especially where there is no access to the gas grid. In many areas the resources may be available to support biomethane injection into the gas grid enabling traditional in-house boilers and gas microCHP to be maintained as a primary source of heat and hot water.

For properties with access to the gas network, gas currently provides a lower carbon solution to heating than electricity. As we decarbonise, the denser suburban areas are likely to move away from gas and on to networked heat extensions or heat pumps. In all of these situations, solar thermal will be able to contribute to total heat demand.

Working for the economy, the consumer and the energy system
Localised power generation from solar, wind and microCHP will reduce CO_2 and could alleviate the increased power demand from heat pumps and electric vehicles. MicroCHP, which generates power at times of peak heat demand, can be integrated in local networks to provide an effective complement to rising demand from electrical heating.

Rural

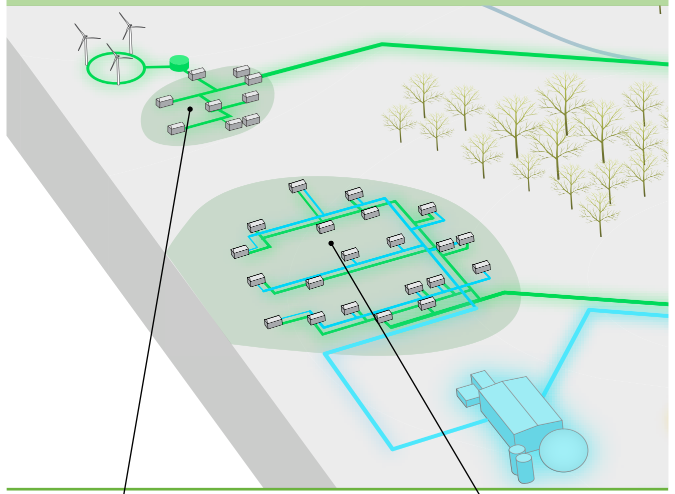
LPG microCHP



Biomass boiler

Ground source heat pump

Where is it happening?



Low density village off gas grid, with local electricity generation

Low density village on gas grid, with biogas from local anaerobic digestion

Off gas grid, LPG microCHP: Lodge Farm, Ruddington, Nottinghamshire

- Lodge Farm, consisting of parklands, stables, farmhouse and summer house with pool, sauna, hot tub, kitchen and living area, is set in the Nottinghamshire countryside.
- With no access to the gas grid fuel must be delivered and LPG represents a lower carbon option than coal or oil.
- LPG is stored in underground tanks equipped with Calor's telemetry system which automatically orders fuel when stocks are low.
- The highly efficient LPG Baxi Ecogen microCHP looks like a regular gas boiler, and uses a Stirling engine to produce heat and up to 1kW of electricity while reducing carbon emissions.
- Fuel bills are cut as on-site generation offsets the amount of electricity to be purchased and, excess electricity can be sent to the grid.

Rural

Now: Individual fossil and electric heating

Heat pumps increase, growth in bioenergy boilers and microCHP

Future: Heat pumps, bioenergy boilers and microCHP

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